DESIGN AND SIMULATION OF HYDRAULIC SHAKING TABLE

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UNIVERSITI TEKNOLOGI MALAYSIA

PSZ 19:16 (Pind. 1/97)

UNIVERSITI TEKNOLOGI MALAYSIA

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SESI PENGAJIAN: 2005/2006

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Degree: **Master of Engineering (Mechanical)**

Faculty: **Mechanical Engineering**

Year: **2005**

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DESIGN AND SIMULATION OF HYDRAULIC SHAKING TABLE

KHAIRULNIZAM BIN NGADIMON

A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Mechanical)

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"I hereby declare that this thesis entitled 'Design and Simulation of Hydraulic Shaking Table' is the result of my own research except those cited in the references."

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To my beloved family,
The lover in you who brings my dreams comes true,

To my child Luqmanul Hakim and Fatin Nur Atikah, who have brought
a new level of love, patience and understanding
into our lives.

ACKNOWLEDGEMENTS

First and above all, I am very grateful to Allah, with his blessing, allow me to complete this project on time.

I would like to take this opportunity to express my deep sense of gratitude and appreciation to my project advisor, Associate Professor Yahaya B. Ramli. His endless help, useful information, support, advice and guidance have made it possible for me to finish the project successfully.

I would also like to express my heartfelt thanks to my project co-advisor Associate Professor Dr. Musa Mailah for the information and motivation to the project. Not to forget Pn. Rosmawati from Structural Engineering Lab, Faculty of Civil Engineering UTM Skudai, En. Asmadi from Bahagian Seismologi, Jabatan Kajicuaca Malaysia for their expert advice. Also thanks to the technicians in the structural lab for their guidance and technical advice. I am also indebted to Kolej Universiti Teknologi Tun Hussein Onn and Jabatan Perkhidmatan Awam, Malaysia for funding my Master study.

Finally, utmost thanks to my parents, my wife Siti Zubaidah and my lovely son and daughter, there are no words that can replace their support, sacrifice and encouragement. Last but not least to my colleagues and friends for the livelihood.

ABSTRACT

Recent industrial progress and computational technology made it possible to construct more complex structures. Vibration of these structures due to seismic strength must be measured and proved to prevent them from damage when they are subjected to earthquake. However, the accuracy of estimating the effect of vibrating structures is limited by the mathematical models, which are normally simplified from the actual complex structures. Due to this problem, a study on the development of shaking table is proposed. The main purpose of this study is to obtain the design specifications for a 1-axis (horizontal) hydraulic shaking table with medium loading, which can function primarily as an earthquake simulator and a dynamic structural testing apparatus. The project employs a three stage electrohydraulic servovalve, actuator system complete with hydraulic system as the power and drive unit. Mathematical model for closed loop control experimentation was presented and used to investigate the influence of various parameters on the overall system. The investigation includes the study on the effect of controller gain setting (for PD and AFC), disturbances and system stability. Time domain analysis using computer simulation was conducted to explain and predict the system's response. Comparison between PD and PD-AFC controllers was done and it was found that latter PD-AFC fulfills the performance and robustness specifications for this project. Other design outcome that limits the change of disturbances on the system was also identified and taken as the framework for real world. This suggests that the next stage in implementation of the designed system can be made for the purpose of an earthquake simulator, since it works very well especially at low frequency level of shaking (0 to 5 Hz).

ABSTRAK

Perkembangan dan kemajuan teknologi terkini dalam bidang industri dan perkomputeran membolehkan struktur bangunan yang lebih kompleks dibina. Getaran struktur bangunan ini terhadap gegaran sismik perlu diukur dan dibuktikan untuk mencegah daripada kerosakan teruk apabila gempa bumi sebenar berlaku. Walaubagaimanapun, untuk struktur yang kompleks, penganggaran kesan getarannya menggunakan model matematik adalah terhad disebabkan beberapa anggapan dalam analisa dinamiknya. Disebabkan masalah ini, telah membawa kepada perkembangan alat lantai gegaran hidraulik. Tujuan utama kajian ini adalah untuk merekabentuk spesifikasi alat lantai gegaran hidraulik 1 paksi (mendatar) pada skala beban yang sederhana. Ianya digunakan untuk tujuan simulator gempa bumi dan untuk menguji pelakuan dinamik sesuatu model atau prototaip struktur. Projek ini menggunakan peringkat ketiga injap servo elektrohidraulik, sistem penggerak lelurus dan sistem hidraulik sebagai unit kuasa dan penggerak. Model matematik untuk ujian kawalan gelung tertutup telah dibincangkan dan digunakan untuk mengkaji kesan beberapa parameter terhadap keseluruhan sistem. Kesan yang dikaji termasuk penetapan pemalar pengawal, kesan pengawal PD dan AFC, kesan gangguan dan kestabilan sistem. Analisa dalam domain masa menggunakan simulasi komputer telah dijalankan untuk mengenalpasti kelakuan sistem. Perbandingan antara pengawal PD dan PD-AFC dikaji dan didapati pengawal PD-AFC memenuhi keperluan spesifikasi sambutan masa dan kelasakannya untuk kajian ini. Parameter lain hasil daripada simulasi yang menghadkan kelakuan sistem daripada kelakuan asalnya juga telah dikenalpasti dan dijadikan asas dalam aplikasi sebenar. Secara keseluruhannya, fasa untuk membangunkan sistem yang telah direkabentuk ini boleh dilakukan untuk tujuan simulasi gempa bumi kerana ianya berfungsi dengan baik terutamanya pada lingkungan frekuensi 0 hingga 5 Hz.

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β	-	Bulk modulus
V	-	Volume
dP	-	Change in pressure
dV	-	Change in volume
F	-	Force
μ	-	Coefficient of friction
N	-	Normal force
Q_E	-	Input flow rate into the cylinder's blank end side
v	-	Extending velocity of the cylinder rod.
q_E	-	Output flow rate from the cylinder's rod end side
a'	-	Cross sectional area of the piston on the rod end side
A	-	Cross sectional area of the piston on the blank end side
D	-	Diameter of piston on the blank end side
d	-	Diameter of piston on the rod end side
$p1$	-	Pressure on the blank end side
$p2$	-	Pressure on the rod end side
Q_R	-	Output flow rate from the cylinder's blank end side
u	-	Extending velocity of the cylinder rod
q_R	-	Input flow rate into the cylinder's rod end side
P	-	Pressure
Q	-	Flow rate
$v_{average}$	-	Average extending velocity
BP	-	Burst pressure

t	-	Thickness
D_0	-	Outside diameter
D_i	-	Inside diameter
WP	-	Working pressure
FS	-	Factor of safety
S	-	Tensile strength
η_v	-	Volumetric efficiency
η_m	-	Mechanical efficiency
η_0	-	Overall efficiency
Q_T	-	Theoretical flow rate
T	-	Torque
ω	-	Angular velocity
W_{theory}	-	Theoretical flow rate
W_{actual}	-	Actual power developed by the pump
W	-	Viscous friction factor
B	-	Dry friction
m	-	Total mass
a	-	Acceleration
L	-	Piston rod length
I	-	Second moment of area
E	-	Young Modulus
K	-	Bending coefficient
f	-	Frequency
λ	-	Wavelength
x	-	Stroke length
t	-	Time
V_D	-	Fluid displacement
N	-	Speed rating